

Planetary Ranging

R. W. Tappan

DSN Data Systems Development Section

The planetary ranging assembly (PRA) determines the range, or distance, to spacecraft that are travelling at planetary distances from Earth by measuring the time required for a radio signal to travel to the spacecraft and back. The range data are used to improve the accuracy of the calculation of the spacecraft's orbit and to provide information concerning the charged particle content of space.

The PRA is able to operate at the reduced signal levels because of improvements in the method of maintaining coder lock and detecting the signal in the presence of space noise. It is capable of operation with either S-band or X-band carrier frequencies and offers selectable code types to enable each project to specify the operating mode best suited to its particular mission.

The planetary ranging assembly was installed in the Deep Space Instrumentation Facility (DSIF) to support Mariner Venus/Mercury 1973 and subsequent planetary missions. The PRA installation was necessary because the Mark 1A lunar ranging cannot operate at the signal levels received from spacecraft traveling at planetary distances. The range data are used to improve the spacecraft orbit prediction and to provide information concerning the charged particle content of space in the path between the ground station and the spacecraft.

The planetary ranging assembly contains digital hardware that performs special control and data collecting functions and a small general purpose computer that handles scheduling, computation, and data formatting.

The PRA is part of a ranging system that measures the round-trip time of a radio signal which travels from a ground tracking station to a spacecraft and back. A coded

signal is modulated on an S-band carrier and transmitted to the spacecraft, which detects and retransmits the signal to the tracking station. The signal received at the tracking station is delayed in time by its round trip through space and is shifted in frequency by the doppler effect because of the relative motion between the spacecraft and tracking station. The delay is measured by synchronizing a local model of the code with the transmitted code and then shifting it into alignment with the received signal. In order to detect alignment between the local code (receiver code) and the received signal, it is necessary to clock the receiver coder at the same bit rate that is present on the received signal. This is accomplished by adding the frequency offset due to the doppler effect to the clock frequency of the transmitted signal. The doppler signal derived from the S-band carrier is scaled and used for this purpose. Although the scaling is exact, there is a slow drift between the receiver coder and the received signal because the carrier and the modulation are not delayed by the same

amount when they pass through a medium containing charged particles. This difference, called differenced range vs integrated doppler (DRVID), is measured and output as a data type.

The PRA operates at much lower received signal levels, and therefore at greater distances, than the lunar ranging, primarily because it is implemented to use the carrier doppler signal to keep the receiver coder in step with the received signal, rather than extracting the coder clock directly from the signal. Performance has also been improved by optimizing the ranging code to improve the efficiency of detection, and employing a computer to numerically average the received signal and thus extend the signal range over which useful information can be recovered.

The elements of the PRA that communicate with the computer do so using the DSIF Standard 14-line interface. This computer interface is designed to transfer data reliably over relatively long distances in the electrically noisy environment of the tracking station. The use of a standard interface makes the equipment design independent of the computer assigned to it and enables equipment configurations to be changed more easily.

The PRA provides capability for ranging with either an S-band receiver or an X-band receiver by using the doppler signal from each receiver to generate a clock signal. Either of these clocks may be selected to drive the receiver coder; the other one automatically drives a clock generator which permits measurement of DRVID only using the receiver not selected for ranging.

A fixed-frequency relationship must exist between the transmitter coder frequency and the S-band carrier in order for the doppler rate aiding scheme to be workable. The same reference frequency that drives the S-band exciter is used to generate the transmitter coder, making the ratio between the carrier frequency and the transmitter coder frequency a fixed ratio of 1/2048. The clock that drives the receiver coder is derived in a similar manner, except that the doppler adder adds the doppler frequency offset, properly scaled. A doppler signal to which a bias reference frequency has been added is used to avoid the cycle detection problems encountered near zero-frequency doppler. The bias is removed digitally by the doppler

adder. High-frequency logic is required to implement the doppler adder, since additions and subtractions must be performed at an intermediate frequency (66 mHz) to minimize the phase jitter introduced in the receiver coder by the stepwise adjustment of its clock phase. The intermediate frequency is the highest frequency compatible with the high-speed logic used.

The transmitter and receiver coders generate both continuous spectrum and discrete spectrum codes. The code type to be used for the acquisition is selectable at the beginning of each ranging acquisition to enable each project to specify the code type best suited for its particular mission. The continuous spectrum code is a pseudo-noise code composed of six components which are combined into a composite code that is transmitted continuously to the spacecraft. The code power at any one frequency is small, minimizing the possibility of interference with other spacecraft operations; however, only a fraction of the total code power is available to align each of the individual components. The discrete spectrum code is composed of 20 square waves whose frequencies range from approximately 500 kHz to approximately 1 Hz. Each of the frequencies is sequentially transmitted to the spacecraft, so that the total code power is available to align it. The discrete spectrum code can therefore be used at lower received signal levels than the continuous spectrum code. The possibility of interference with other spacecraft operations has been reduced by mixing all components of this code with the highest frequency component.

The planetary ranging assembly was installed in the DSIF to provide range and DRVID data from spacecraft traveling at planetary distances. The measurement of range is used to improve the prediction of the spacecraft's orbit, and the DRVID data disclose information concerning the charged particle content of space.

Ranging at planetary distances is possible because of the performance improvement resulting from the incorporation of doppler rate aiding, code optimization, and numerical averaging of the received signal.

The PRA incorporates the flexibility necessary to support future missions by providing both continuous and discrete spectrum codes which may be used with either S-band or X-band carriers.

Bibliography

1. Tausworthe, R. C., "Ranging Measurement," in *Supporting Research and Advanced Development*, Space Programs Summary 37-42, Vol. III, Jet Propulsion Laboratory, Pasadena, Calif., Nov. 30, 1966, pp. 52-56.
2. Tausworthe, R. C., "Communications Systems Development Minimizing Range Code Acquisition Time," in *Supporting Research and Advanced Development*, Space Programs Summary 37-42, Vol. IV, Jet Propulsion Laboratory, Pasadena, Calif., Dec. 31, 1966, pp. 198-200.
3. Martin, W. L., "Special Equipment for Mariner Venus 67 Ranging System," in *Supporting Research and Advanced Development*, Space Programs Summary 37-48, Vol. III, Jet Propulsion Laboratory, Pasadena, Calif., Nov. 30, 1967, pp. 63-67.
4. Lushbaugh, W. A., "Mariner Venus 67 Ranging System Digital Rack," in *The Deep Space Network*, Space Programs Summary 37-50, Vol. II, Jet Propulsion Laboratory, Pasadena, Calif., March 31, 1968, pp. 56-61.
5. Goldstein, R. M., "Ranging With Sequential Components," in *The Deep Space Network*, Space Programs Summary 37-52, Vol. II, Jet Propulsion Laboratory, Pasadena, Calif., July 31, 1968, pp. 46-49.
6. Martin, W. L., "A Binary-Coded Sequential Acquisition Ranging System," in *The Deep Space Network*, Space Programs Summary 37-57, Vol. II, Jet Propulsion Laboratory, Pasadena, Calif., May 31, 1969, pp. 72-81.
7. Lindley, I. P., *The PN Technique of Ranging as Applied in the Ranging Subsystem Mark I*, Technical Report 32-811, Jet Propulsion Laboratory, Pasadena, Calif., Nov. 15, 1965.
8. *Planetary Ranging Assembly Functional Requirements Document*, FM509136, Sept. 27, 1973 (JPL internal document).
9. *Planetary Ranging Assembly Technical Manual*, TM509201, Sept. 15, 1973 (JPL internal document).

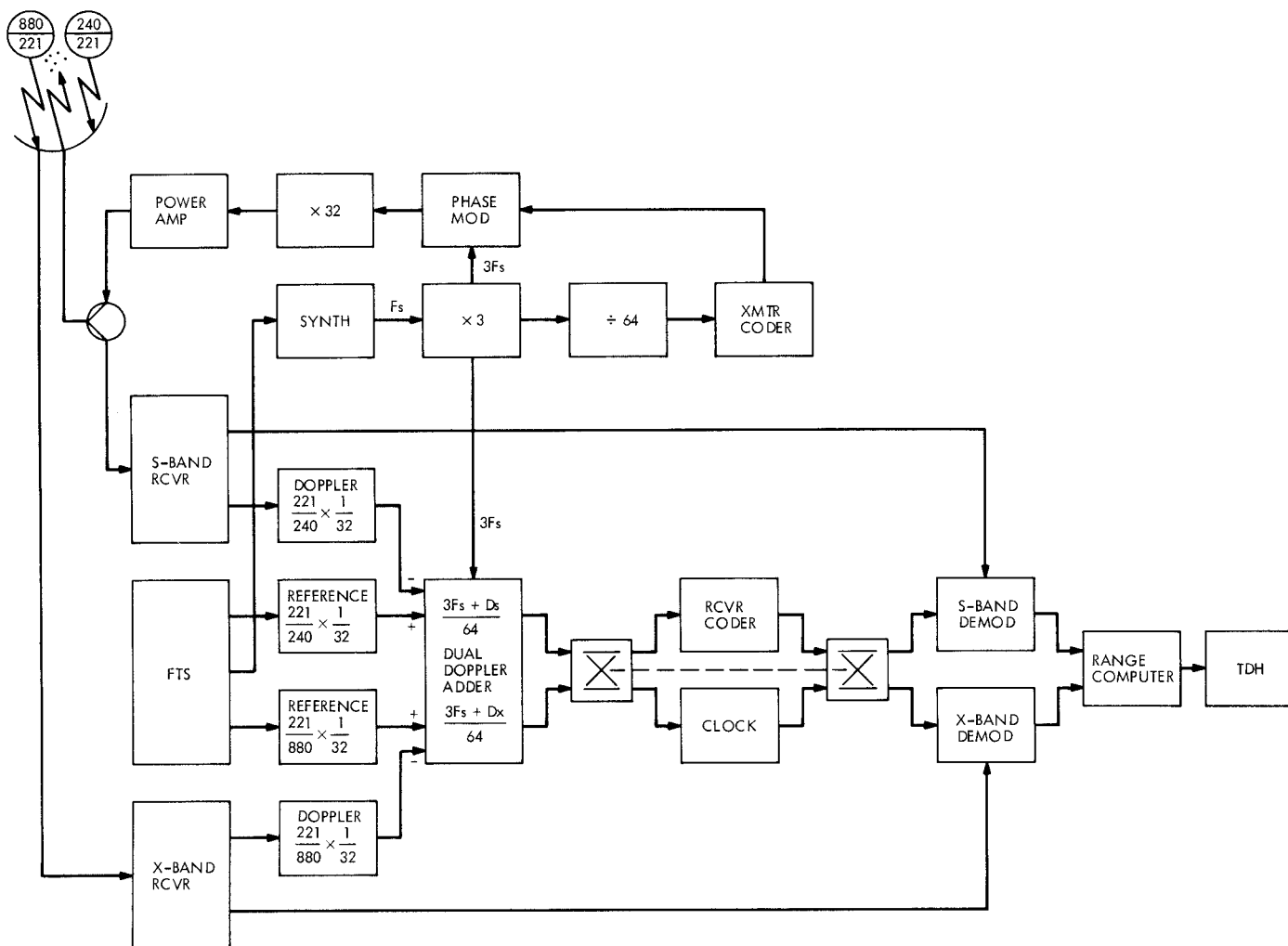


Fig. 1. Planetary ranging block diagram